TABLE 9

SOURCES OF GROWTH IN FACTOR PRICES AND PRODUCT PRICES; ELASTICITIES OF SUBSTITUTION AND TRANSFORMATION, 1929–1967 (ANNUAL PERCENTAGE RATES OF GROWTH)

	1929–1948	1948–1967	1929–1967
1. Labor cost			
a. Stock	4.03	4.72	4.37
b. Potential flow	3.43	3.98	3.71
c. Actual flow	3.56	4.09	3.83
2. Capital cost			
a. Stock	3.66	3.03	3.34
b. Potential flow	3.35	2.10	2.72
c. Actual flow	2.47	1.83	2.15
3. Elasticity of substitution			
a. Stock	−2.69	1.40	0.66
b. Potential flow	−16.15	1.36	0.64
c. Actual flow	−0.25	1.30	0.79
d. ACMS	−0.20	1.35	0.77
4. Consumption goods price	2.13	1.97	2.05
5. Investment goods price	2.22	1.81	2.02
6. Elasticity of transformation	6.13	−2.07	−16.10

factor proportions and relative factor prices in analyzing the responsiveness of factor proportions to factor price changes. We have also analyzed the responsiveness of product proportions to product price changes. We now consider the application of real product and real factor input to the measurement of total factor productivity. We present a number of alternative estimates of total factor productivity based on alternative conventions about the measurement of real factor input. We begin with an estimate of total factor productivity based on the actual flow of labor and capital services. We compare this estimate with alternatives based on potential flows of labor and capital services and on stocks of labor and capital.

The services of consumers' durables and producers' durables used by institutions are allocated directly to final demand so that growth in the quantities of these services does not affect growth of total factor productivity. Similarly, the services of owner-occupied dwellings and institutional structures are allocated directly to final demand. In evaluating the relative importance of growth of real factor input and of total factor productivity as sources of economic growth, it is useful to compare the relative proportions of each on the growth of real product, including and excluding capital services from the household sector. We present estimates of the relative importance of the sources of economic growth for gross private domestic product as we have defined it and for analogous gross product measures excluding household durables and structures.

Total factor productivity is defined as the ratio of real product to real factor input or, equivalently, as the ratio of the price of factor input to the product price. Growth in total factor productivity has a counterpart in growth of the price of factor input relative to the price of output. We may define a Divisia index of total factor productivity, say P, as:

$$\log\frac{P_t}{P_{t-1}} = \log\frac{Y_t}{Y_{t-1}} - \log\frac{X_t}{X_{t-1}},$$

where Y is the quantity index of total product and X is the quantity index of total factor input. Equivalently, the index of total factor productivity may be defined as:

$$\log \frac{P_t}{P_{t-1}} = \log \frac{p_t}{p_{t-1}} - \log \frac{q_t}{q_{t-1}},$$

where p is the price index of total factor input and q is the price index of total product.[35] The index of total factor productivity for 1929–1967 corresponding to the quantity index of gross private domestic product from Table 3 and the quantity index of gross private domestic factor input from Table 6 is given in Table 10.

The conventions for measurement of factor services underlying our concept of gross private domestic factor input have been employed by Jorgenson and Griliches. Our estimates differ from theirs in two significant respects: First, we have converted their index of relative utilization to an annual basis and reduced the scope of adjustments of potential flows of capital services for changes in relative utilization. Second, we have measured the flow of capital services for sectors distinguished by legal form of organization in order to provide a more detailed representation of the tax structure. These differences have an important impact on the estimate of total factor productivity.

Our conventions for the measurement of factor services are not the only ones employed in the measurement of total factor productivity. Denison and Solow use a stock concept of capital input, measuring neither changes in relative utilization nor changes in the quality of capital services due to changes in the composition of the capital stock.[36] Denison weights persons engaged by an index of labor quality that incorporates the effects of growth in educational attainment but differs in a number of important respects from the index we have used.[37] Denison also adjusts man-hours for changes in labor efficiency that accompany changes in hours per man.[38] Solow uses unweighted man-hours, omitting the effects of changes in the composition of the labor force on the quantity of labor input.[39] Kendrick adjusts labor and capital input for changes in the industrial composition of labor force and capital stock.[40] However, changes within an industrial sector due to shifts in composition are not included in his measures of real factor input.

To provide a basis for comparison of our estimates of total factor productivity with estimates that result from alternative conventions for the measurement of real factor input, we present measures of total factor productivity based on potential service flows and on stocks of labor and capital in Table 10. The first variant on our estimate of total factor productivity omits the relative utilization adjustment for capital, the second omits the relative utilization adjustment for

[35]For further discussion of this index of total factor productivity, see Jorgenson and Griliches [23], especially pages 250–254. The Divisia index of total factor productivity described in the text is a discrete approximation to the continuous Divisia index discussed by Jorgenson and Griliches.

[36]See Denison [10], pages 94–99, and Solow [32], page 315.

[37]See Denison [10], especially pages 67–72.

[38]See Denison [10], especially pages 35–41.

[39]See Solow [32], page 315.

[40]See Kendrick [26], especially pages 252–289.

TABLE 10

TOTAL FACTOR PRODUCTIVITY, 1929–1967 (1958 = 1.000)

Year	1. Labor and Capital Services	2. Actual Labor Services; Potential Capital Services	3. Potential Labor and Capital Services	4. Potential Labor Services; Capital Stock	5. Labor and Capital Stock	6. Actual Labor Services; Capital Stock	7. Unweighted Man-hours; Capital Stock
1929	0.726	0.685	0.707	0.664	0.599	0.644	0.530
1930	0.680	0.631	0.652	0.614	0.555	0.595	0.496
1931	0.657	0.600	0.628	0.591	0.536	0.565	0.483
1932	0.614	0.550	0.567	0.533	0.484	0.517	0.445
1933	0.604	0.548	0.564	0.527	0.480	0.511	0.443
1934	0.636	0.586	0.596	0.552	0.504	0.543	0.487
1935	0.668	0.627	0.640	0.593	0.543	0.581	0.518
1936	0.714	0.679	0.696	0.645	0.592	0.629	0.556
1937	0.738	0.699	0.719	0.669	0.615	0.650	0.571
1938	0.734	0.679	0.695	0.649	0.599	0.634	0.567
1939	0.763	0.724	0.743	0.694	0.642	0.676	0.601
1940	0.788	0.766	0.786	0.736	0.682	0.716	0.638
1941	0.826	0.828	0.851	0.799	0.744	0.777	0.692
1942	0.839	0.855	0.882	0.832	0.778	0.807	0.715
1943	0.872	0.912	0.941	0.888	0.834	0.860	0.758
1944	0.925	0.969	1.005	0.946	0.893	0.913	0.807
1945	0.944	0.973	1.004	0.945	0.896	0.916	0.822
1946	0.898	0.908	0.930	0.878	0.836	0.857	0.790

1947	0.862	0.878	0.895	0.852	0.815	0.836	0.782
1948	0.882	0.896	0.911	0.876	0.843	0.862	0.814
1949	0.892	0.890	0.904	0.875	0.845	0.861	0.817
1950	0.938	0.948	0.961	0.935	0.906	0.922	0.882
1951	0.946	0.960	0.971	0.949	0.923	0.938	0.902
1952	0.949	0.956	0.967	0.949	0.927	0.938	0.904
1953	0.968	0.982	0.990	0.974	0.954	0.966	0.938
1954	0.974	0.977	0.982	0.969	0.953	0.964	0.942
1955	1.006	1.022	1.031	1.020	1.006	1.012	0.989
1956	0.993	1.010	1.018	1.011	1.001	1.004	0.986
1957	0.998	1.009	1.012	1.009	1.002	1.006	0.996
1958	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1959	1.018	1.034	1.038	1.039	1.046	1.035	1.039
1960	1.019	1.036	1.040	1.043	1.056	1.039	1.048
1961	1.032	1.046	1.048	1.054	1.072	1.053	1.068
1962	1.061	1.085	1.088	1.097	1.120	1.094	1.114
1963	1.076	1.104	1.106	1.119	1.147	1.116	1.141
1964	1.091	1.130	1.134	1.151	1.185	1.147	1.177
1965	1.115	1.157	1.162	1.187	1.226	1.181	1.215
1966	1.129	1.174	1.178	1.211	1.258	1.207	1.249
1967	1.114	1.157	1.162	1.204	1.256	1.199	1.247

labor; the second variant is based on potential service flows for both labor and capital input. The third variant omits the quality adjustment for capital, while the fourth omits the quality adjustment for labor, providing a stock measure of total factor productivity. Two final variants provide combinations of alternative measures of labor input with the stock measure of capital. The fifth combines actual labor input with the stock of capital, while the sixth combines unweighted actual man-hours with capital stock.

TABLE 11
GROWTH IN TOTAL FACTOR PRODUCTIVITY, 1929–1967 (AVERAGE ANNUAL RATES OF GROWTH)

	1929–1948	1948–1967	1929–1967
1. Actual labor and capital services	1.03	1.23	1.13
2. Actual labor services; potential capital services	1.42	1.35	1.38
3. Potential labor and capital services	1.34	1.28	1.31
4. Potential labor services; capital stock	1.46	1.67	1.56
5. Labor and capital stock	1.80	2.10	1.95
6. Actual labor services; capital stock (Denison)	1.54	1.74	1.64
7. Man-hours and capital stock (Solow and ACMS)	2.26	2.25	2.25

It is obvious from a comparison of the alternative estimates of total factor productivity given in Table 10 that the results are highly sensitive to the choice of conventions for measuring real factor input. The effects of varying the conventions are summarized for the periods 1929–1948, 1948–1967, and 1929–1967 in Table 11; geometric average annual rates of growth are given for each variant of total factor productivity.

Finally, to evaluate the relative importance of growth in real factor input and growth in total factor productivity as sources of economic growth, we consider the relative proportion of growth in real factor input for two alternative concepts of real product—including and excluding the capital input of the household sector. Geometric average annual rates of growth are given for real product and real factor input, including and excluding household capital services, for 1929–1967 in Table 12. The relative proportion of growth in total factor productivity in the growth of real product is also provided for both concepts of real product.[41]

We find that the growth in real factor input predominates in the explanation of the growth of real product for the period 1929–1967 and for each of the sub-periods, 1929–1948 and 1948–1967. These findings are directly contrary to those of Abramovitz [1], Kendrick [26], and Solow [32], in earlier studies of productivity change. We have estimated real factor input on the basis of capital stock and actual man-hours, the conventions used by Solow and subsequently adopted by Arrow, Chenery, Minhas, and Solow [2], for 1929–1967. The resulting

[41]Denison [10], pages 148–149, employs real national income, Solow [32], page 315, employs private, non-farm, gross national product, and Kendrick [26], pages 328–342, employs both gross national product and net national product.

TABLE 12

THE RELATIVE IMPORTANCE OF PRODUCTIVITY CHANGE, 1929–1967 (AVERAGE ANNUAL RATES OF GROWTH)

	1929–1948	1948–1967	1929–1967
1. Gross private domestic product			
Real product	2.37	3.96	3.16
Real factor input	1.34	2.73	2.04
Total factor productivity	1.03	1.23	1.13
Relative proportion of productivity change	0.43	0.31	0.36
2. Gross private domestic product, excluding household capital services			
Real product	2.54	3.70	3.12
Real factor input	1.54	2.28	1.91
Total factor productivity	1.00	1.42	1.21
Relative proportion of productivity change	0.39	0.38	0.39

estimates of the distribution of the growth of real product between growth in real factor input and total factor productivity are comparable to those of Solow's earlier study. On this basis total factor productivity grows at the average rate of 2.25 per cent per year while real factor input grows at 0.91 per cent per year. Our estimates, given in Table 12, are that total factor productivity grows at 1.13 per cent per year and real factor input at the rate of 2.04 per cent per year. Total factor productivity accounts for 36 per cent of the growth of real product, while real factor input accounts for 64 per cent of output growth.

We have also extended estimates of real factor input based on capital stock and actual labor input, the conventions adopted by Denison [10], through 1967. Denison's estimates of the growth of labor input are conceptually similar to our own and his empirical results are closely comparable to ours. We find that estimates of real factor input based on the conventions used by Denison suggest that total factor productivity grows at the average rate of 1.64 per cent per year while real factor input grows at 1.52 per cent per year. The discrepancy between our estimates, given in Table 12, and those of Denison is accounted for almost entirely by our adjustments of the measure of capital input for quality change and relative utilization. Denison has incorporated about half the growth in real factor input over and above the growth of capital stock and actual man-hours into his estimates of real factor input.

Finally, although growth in real factor input predominates in the growth of real product, we estimate that changes in total productivity are substantial for 1929–1967 and for both the sub-periods we have considered. The conclusion of Jorgenson and Griliches [23] that productivity growth is negligible must be revised accordingly. The main differences between our estimates and those of Jorgenson and Griliches are in the measurement of capital. We have incorporated the effects of taxation in greater detail through separation of property compensation by legal form of organization. However, the discrepancy between our empirical results and those of Jorgenson and Griliches is primarily accounted for by our measurement of the relative utilization of capital. We have reduced the scope of the adjustment for relative utilization by confirming it to depreciable assets in the corporate and non-corporate sectors. Second, incorporation of

annual estimates of capacity to consume electricity and actual electricity consumption results in the allocation of the total growth in relative utilization for the period 1929–1967 to the period 1929–1948. In the relative utilization adjustment of Jorgenson and Griliches, almost all of the growth in relative utilization was allocated to the period 1945–1965.

7. Summary and Conclusion

In this paper we have attempted to provide a conceptual basis for separating social product and social factor input into price and quantity components. To test the feasibility of our accounting framework we have measured real product and real factor input for the United States from 1929–1967. We conclude that estimates of real factor input paralleling the real product estimates in the United States national accounts are feasible. The data required for estimation of real product are the same as those required for perpetual inventory estimates of capital stock together with data on property compensation by legal form of organization and information on the tax structure for property income.

Fully satisfactory estimates of real factor input will require much additional research. In measuring labor input, data on persons engaged should include estimates of the number of unpaid family workers, such as those of Kendrick [25, 26]. Estimates of man-hours for the different components of the labor force should be compiled on a basis consistent with data on persons engaged, as Kendrick [25, 26] has done. The weakest link in the chain of imputations linking labor input to the underlying data on man-hours and employment is the adjustment of labor input for the intensity of effort, along the lines suggested by Denison [10]. Additional evidence on this adjustment is given by Denison [11] for the United States and for Europe. The validity of estimates of intensity of effort must be tested through the study of variations in labor income by hours worked, holding other characteristics of labor input constant. Finally, the quality adjustments for the labor force should be expanded to incorporate changes in the relative number of hours worked. The quality adjustments should also incorporate characteristics of the labor force other than educational attainment such as age, race, sex, occupation, and industry. Similar improvements in the measurement of capital input are discussed in our previous paper.[42]

Detailed accounting measurements of real product and real factor input will open up many new possibilities for the study of production. We have analyzed the responsiveness of factor proportions to changes in relative factor prices and the responsiveness of product proportions to changes in relative product prices. Average elasticities of substitution between factors and transformation between products vary considerably between the sub-periods 1929–1948 and 1948–1967. Estimates of these elasticities depend critically on the method for measurement of factor input. Our estimates of the elasticity of substitution, based on actual flows of labor and capital input, are strikingly similar to those of Arrow, Chenery, Minhas, and Solow [2], based on very different conventions of measurement. However estimates of the elasticity of substitution based on stocks

[42]Christensen and Jorgenson [5].

of labor and capital or potential flows of labor and capital services differ substantially from these estimates.

We have measured total factor productivity in the United States for the period 1929–1967. This study extends the analysis of productivity change by Jorgenson and Griliches [23]. First, we have provided measurements for a considerably longer time period than the time period 1945–1965 used in their study. Second, we have analyzed the growth of real factor input in more detail. One important change is the refinement of the measurement of relative utilization of capital by incorporation of annual data on capacity to consume electricity and on actual electricity consumption. A second important change is the separation of property compensation by legal form of organization. This change enables us to incorporate the effects of taxation of income from capital in a more satisfactory way.

Although growth in real factor input predominates in the growth of real product, we estimate that changes in total factor productivity are substantial for 1929–1967 and for both the sub-periods we have considered. The conclusion of Jorgenson and Griliches that productivity growth is negligible must be revised accordingly.

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